Figure 1

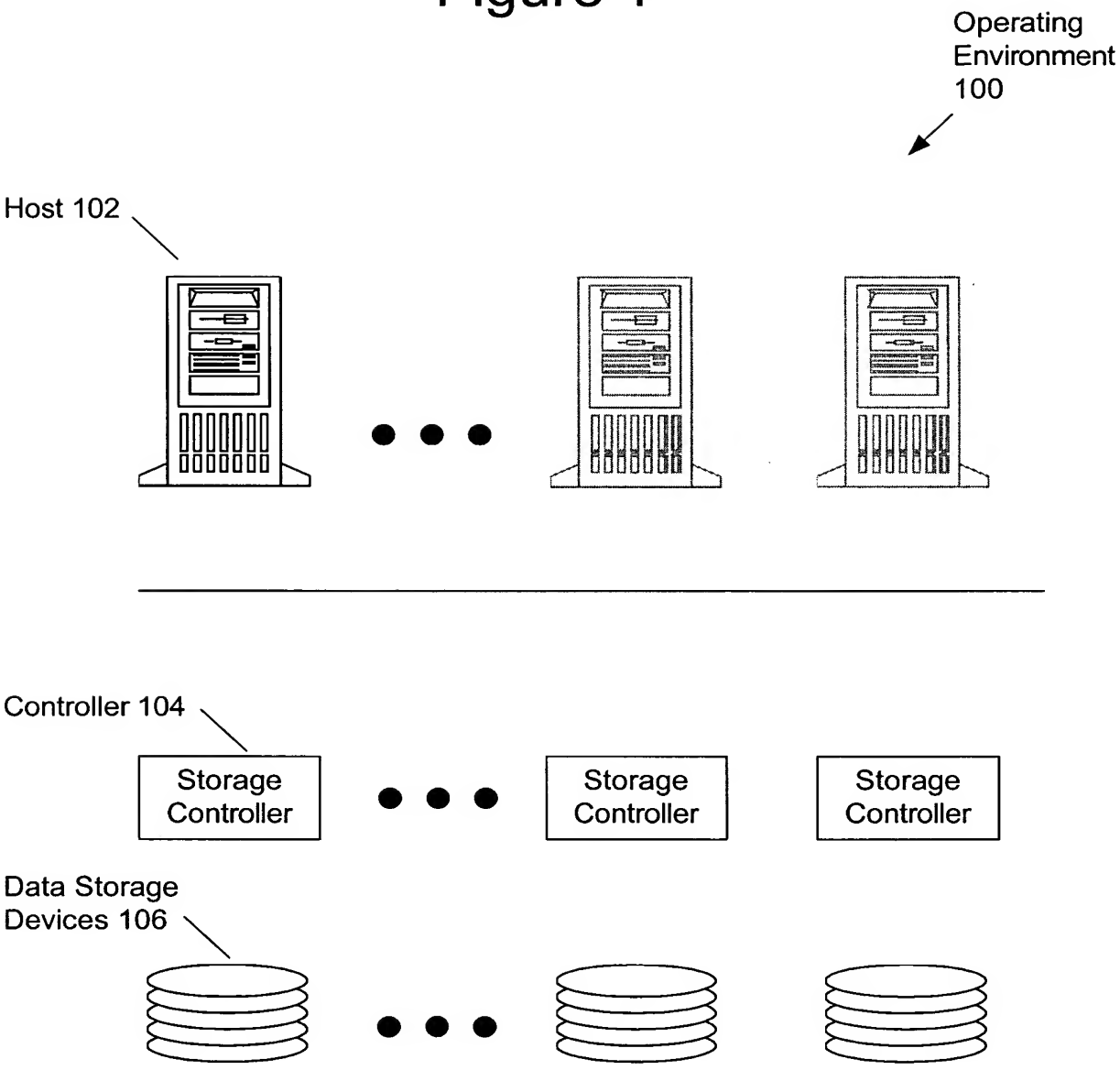

Operating Environment 100
Host 102
Controller 104
Storage Controller
Storage Controller
Storage Controller
Data Storage Devices 106

Figure 2

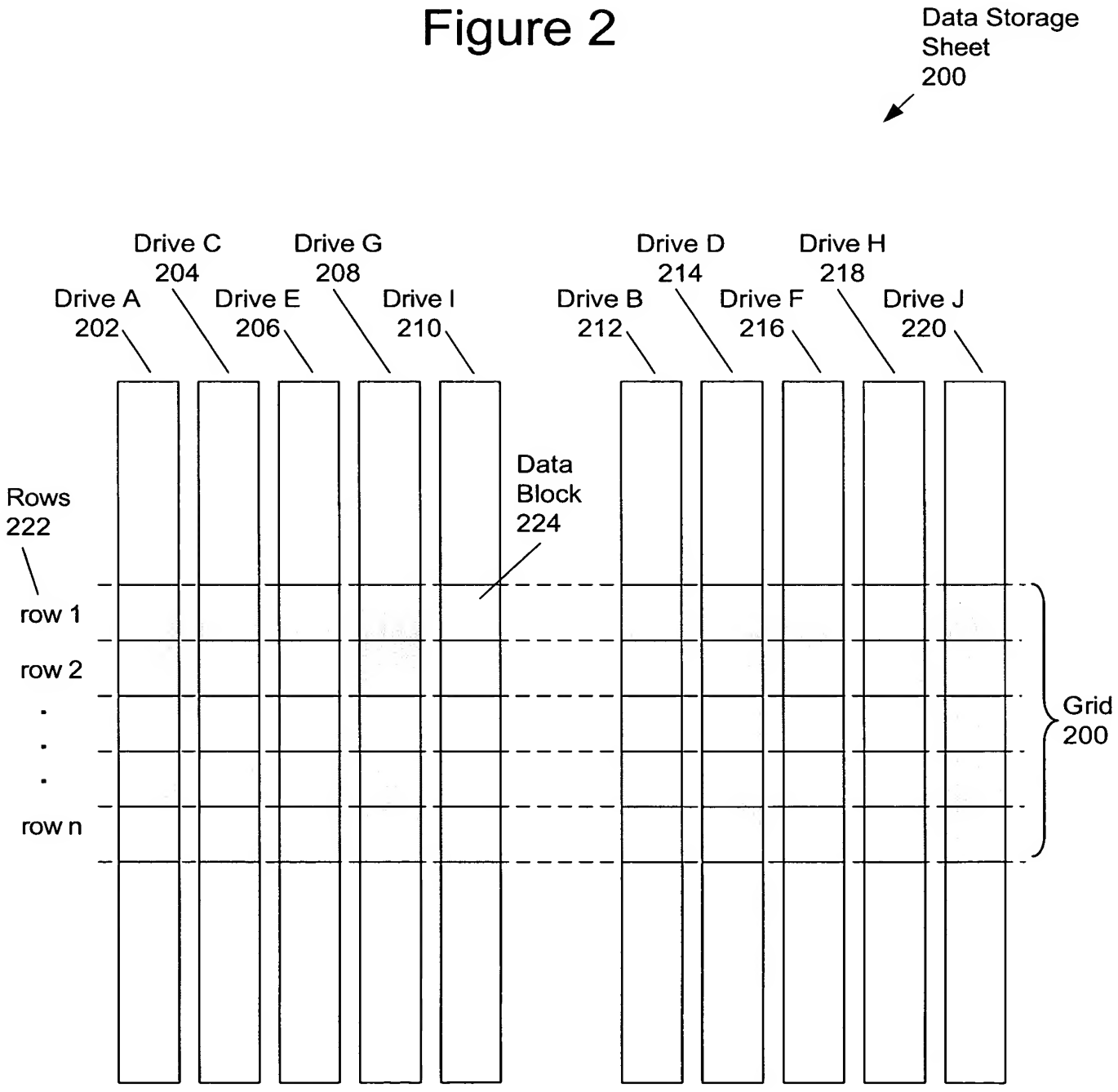

Data Storage Sheet 200
Drive A 202
Drive C 204
Drive E 206
Drive G 208
Drive I 210
Drive B 212
Drive D 214
Drive F 216
Drive H 218
Drive J 220
Rows 222
Data Block 224
row 1
row 2
row n
Grid 200

Figure 3

Sparing Table 300

304 Sparing Versions

302 Drives

Drives / Version	A	C	E	G	I		B	D	F	H	J
SV1	u	u	u	u	s		u	u	u	u	s
SV2	u	u	u	s	u		u	u	u	s	u
SV3	u	u	s	u	u		u	u	s	u	u
SV4	u	s	u	u	u		u	s	u	u	u
SV5	s	u	u	u	u		s	u	u	u	u

Group 1 Drives 306

Group 2 Drives 308

Figure 4A

Chapter Table 400

Paragraphs 402 | Group 1 Drives 404 | Group 2 Drives 406 | Spare Drives 408

Paragraph	Group 1	Group 2	Spare
1	A C E G	B D F H	I J
2	C E G I	D F H J	A B
3	G A I E	H B J F	C D
4	A I G C	B J H D	E F
5	E A C I	F B D J	G H

Figure 4B

Capacity Grid 410

Group 1 412 | Group 2 414

A	C	E	G	B	D	F	H
A	C	E	G	B	D	F	H
A	C	E	G	B	D	F	H
A	C	E	G	B	D	F	H
A	C	E	G	D	D	F	H

Figure 5A

Single Row
RAID-0 Grid
500

Data A-1	Data A-2	Data A-3	Data A-4	Data B-1	Data B-2	Data B-3	Data B-4

Figure 5B

Two Row
RAID-0 Grid
502

Data A-1	Data A-2	Data A-3	Data A-4	Data B-1	Data B-2	Data B-3	Data B-4
Data C-1	Data C-2	Data C-3	Data C-4	Data D-1	Data D-2	Data D-3	Data D-4

Figure 5C

Five Row
RAID-0 Grid
504

Data A-1	Data A-2	Data A-3	Data A-4	Data B-1	Data B-2	Data B-3	Data B-4
Data C-1	Data C-2	Data C-3	Data C-4	Data D-1	Data D-2	Data D-3	Data D-4
Data E-1	Data E-2	Data E-3	Data E-4	Data F-1	Data F-2	Data F-3	Data F-4
Data G-1	Data G-2	Data G-3	Data G-4	Data H-1	Data H-2	Data H-3	Data H-4
Data I-1	Data I-2	Data I-3	Data I-4	Data J-1	Data J-2	Data J-3	Data J-4

Figure 6A

Single Row RAID-1 Grid 600

Data A-1	Data A-2	Data A-3	Data A-4	Data A-1	Data A-2	Data A-3	Data A-4

Figure 6B

Two Row RAID-1 Grid 602

Data A-1	Data A-2	Data A-3	Data A-4	Data B-1	Data B-2	Data B-3	Data B-4
Data B-1	Data B-2	Data B-3	Data B-4	Data A-1	Data A-2	Data A-3	Data A-4

Figure 6C

Five Row RAID-1 Grid 604

Data A-1	Data A-2	Data A-3	Data A-4	Data B-1	Data B-2	Data B-3	Data B-4
Data C-1	Data C-2	Data C-3	Data C-4	Data D-1	Data D-2	Data D-3	Data D-4
Data E-1	Data E-2	Data E-3	Data E-4	Data A-1	Data A-2	Data A-3	Data A-4
Data B-1	Data B-2	Data B-3	Data B-4	Data C-1	Data C-2	Data C-3	Data C-4
Data D-1	Data D-2	Data D-3	Data D-4	Data E-1	Data E-2	Data E-3	Data E-4

Figure 7

RAID-5
Grid
700

Data A-1	Data A-2	Data A-3	Data A-4	Data B-1	Data B-2	Data B-3	Data B-4
Data C-1	Data C-2	Data C-3	Data C-4	Data D-1	Data D-2	Data D-3	Data D-4
Data E-1	Data E-2	Data E-3	Data E-4	Data F-1	Data F-2	Data F-3	Data F-4
Data G-1	Data G-2	Data G-3	Data G-4	Data H-1	Data H-2	Data H-3	Data H-4
PB	PD	PF	PH	PA	PC	PE	PG

Figure 8A

RAID-0 Grid 800

A	A	A	A	B	B	B	B
C	C	C	C	D	D	D	D
E	E	E	E	F	F	F	F
G	G	G	G	H	H	H	H
I	I	I	I	J	J	J	J

Figure 8B

RAID-1 Grid 802

A	A	A	A	B	B	B	B
C	C	C	C	D	D	D	D
E	E	E	E	A	A	A	A
B	B	B	B	C	C	C	C
D	D	D	D	E	E	E	E

Figure 8C

RAID-5 Grid 804

A	A	A	A	B	B	B	B
C	C	C	C	D	D	D	D
E	E	E	E	F	F	F	F
G	G	G	G	H	H	H	H
PB	PD	PF	PH	PA	PC	PE	PG

Figure 9A

RAID-0 Grid 900

A	A	A	A	B	B	B	B
C	C	C	C	D	D	D	D
E	E	E	E				
G	G	G	G				

Figure 9B

RAID-1 Grid 902

A	A	A	A	B	B	B	B
C	C	C	C	D	D	D	D
E	E	E	E	A	A	A	A
B	B	B	B	C	C	C	C
D	D	D	D	E	E	E	E

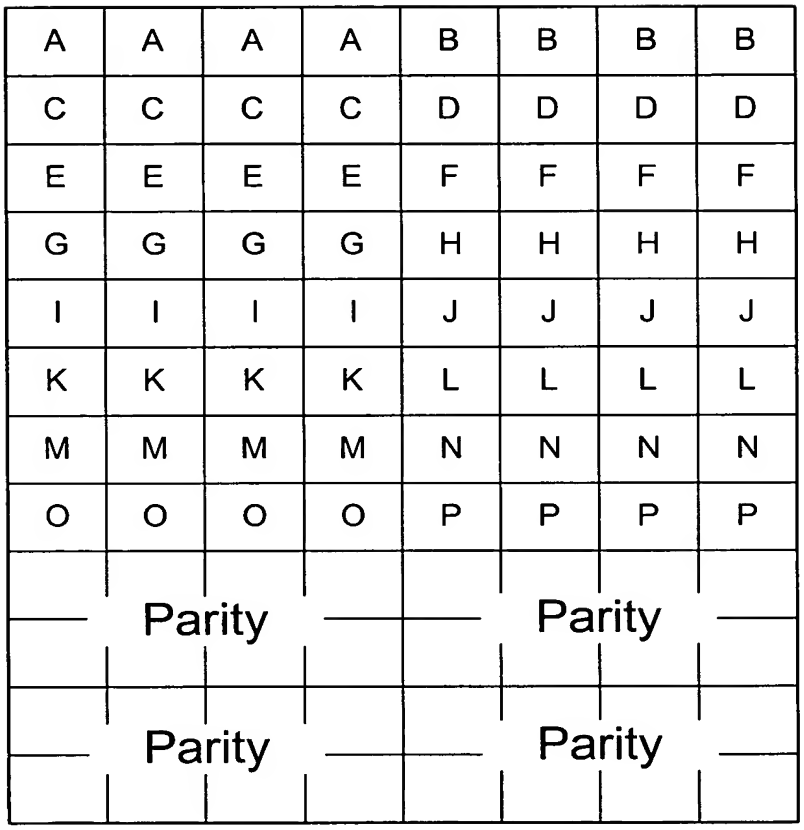
Figure 9C

RAID-5 Grid 904

A	A	A	A	B	B	B	B
C	C	C	C	D	D	D	D
E	E	E	E				
PB	PD			PA	PC	PE	

Figure 10A

RAID 6
Capacity Grid
1000



Data Sets
1002

Figure 10B

RAID 6
Data / Parity
Map
1002

Data
Blocks
1004

Parity
Blocks
1006

A-1	A-2	A-3	A-4	E-5	E-6	E-7	E-8		Data 1
B-8	B-1	B-2	B-3	F-4	F-5	F-6	F-7		
C-7	C-8	C-1	C-2	G-3	G-4	G-5	G-6		
D-6	D-7	D-8	D-1	H-2	H-3	H-4	H-5		
I-10	I-9	I-12	I-11	M-14	M-13	M-16	M-15		
J-9	J-16	J-11	J-10	N-13	N-12	N-15	N-14		
K-16	K-15	K-10	K-9	O-12	O-11	O-14	O-13		
L-15	L-14	L-9	L-16	P-11	P-10	P-13	P-12		
13P	5P	15P	7P	9P	1P	11P	3P		Vertical Parity (VPAR-1)
14P	6P	16P	8P	10P	2P	12P	4P		
EP	MP	FP	NP	AP	IP	BP	JP		Row Parity (RPAR-1)
GP	OP	HP	PP	CP	KP	DP	LP		

Grid Contents
1008

Figure 11

RAID 6
DSU / Parity
Map
1100

Failed Drives
1102

A-1	A-2	A-3	A-4	E-5	E-6	E-7	E-8
B-8	B-1	B-2	B-3	F-4	F-5	F-6	F-7
C-7	C-8	C-1	C-2	G-3	G-4	G-5	G-6
D-6	D-7	D-8	D-1	H-2	H-3	H-4	H-5
I-10	I-9	I-12	I-11	M-14	M-13	M-16	M-15
J-9	J-16	J-11	J-10	N-13	N-12	N-15	N-14
K-16	K-15	K-10	K-9	O-12	O-11	O-14	O-13
L-15	L-14	L-9	L-16	P-11	P-10	P-13	P-12
13P	5P	15P	7P	9P	1P	11P	3P
14P	6P	16P	8P	10P	2P	12P	4P
EP	MP	FP	NP	AP	IP	BP	JP
GP	OP	HP	PP	CP	KP	DP	LP

Data
Blocks
1104

Parity
Blocks
1106

Inaccessible
Blocks
1108

Accessible
Blocks
1110

Figure 12

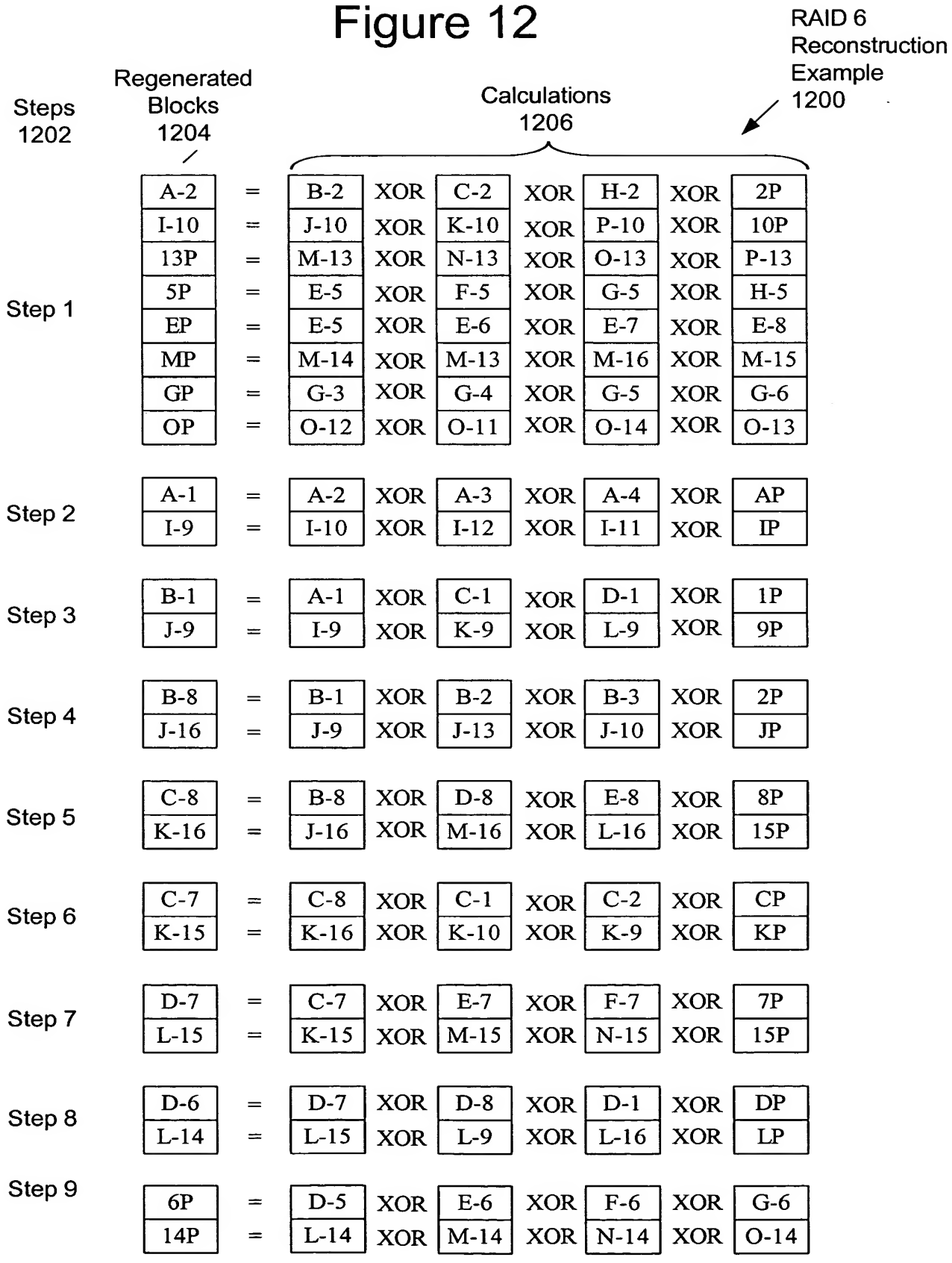

RAID 6 Reconstruction Example 1200
Steps 1202
Regenerated Blocks 1204
Calculations 1206
Step 1
A-2 = B-2 XOR C-2 XOR H-2 XOR 2P
I-10 = J-10 XOR K-10 XOR P-10 XOR 10P
13P = M-13 XOR N-13 XOR O-13 XOR P-13
5P = E-5 XOR F-5 XOR G-5 XOR H-5
EP = E-5 XOR E-6 XOR E-7 XOR E-8
MP = M-14 XOR M-13 XOR M-16 XOR M-15
GP = G-3 XOR G-4 XOR G-5 XOR G-6
OP = O-12 XOR O-11 XOR O-14 XOR O-13
Step 2
A-1 = A-2 XOR A-3 XOR A-4 XOR AP
I-9 = I-10 XOR I-12 XOR I-11 XOR IP
Step 3
B-1 = A-1 XOR C-1 XOR D-1 XOR 1P
J-9 = I-9 XOR K-9 XOR L-9 XOR 9P
Step 4
B-8 = B-1 XOR B-2 XOR B-3 XOR 2P
J-16 = J-9 XOR J-13 XOR J-10 XOR JP
Step 5
C-8 = B-8 XOR D-8 XOR E-8 XOR 8P
K-16 = J-16 XOR M-16 XOR L-16 XOR 15P
Step 6
C-7 = C-8 XOR C-1 XOR C-2 XOR CP
K-15 = K-16 XOR K-10 XOR K-9 XOR KP
Step 7
D-7 = C-7 XOR E-7 XOR F-7 XOR 7P
L-15 = K-15 XOR M-15 XOR N-15 XOR 15P
Step 8
D-6 = D-7 XOR D-8 XOR D-1 XOR DP
L-14 = L-15 XOR L-9 XOR L-16 XOR LP
Step 9
6P = D-5 XOR E-6 XOR F-6 XOR G-6
14P = L-14 XOR M-14 XOR N-14 XOR O-14

Figure 13

Capacity Grid Failed Drives with Sparing 1300

Failed Drives 1302

Sparing Version 1304

1	2	3	4	5

A	B	2	0	2	2	2
A	C	2	1	1	2	2
A	D	2	1	1	2	2
A	E	2	1	2	1	2
A	F	2	1	2	1	2
A	G	2	1	2	2	1
A	H	2	1	2	2	1
A	I	1	1	2	2	2
A	J	1	1	2	2	2
B	C	2	1	1	2	2
B	D	2	1	1	2	2
B	E	2	1	2	1	2
B	F	2	1	2	1	2
B	G	2	1	2	2	1
B	H	2	1	2	2	1
B	I	1	1	2	2	2
B	J	1	1	2	2	2
C	D	2	2	0	2	2

Failed Columns Within a Capacity Grid 1306

Figure 14A

Chapter Table 1400

Paragraph	Group 1	Group 2	Spare
1	A C E G	B D F H	I J
2	C E G I	D F H J	A B
3	G A I E	H B J F	C D
4	A I G C	B J H D	E F
5	E A C I	F B D J	G H

Figure 14B

Singly Spared Table 1402

Sparing Version	Group 1	Group 2	Spare
1	I C E G	B D F H	J
2	C E G I	D F H J	B
3	G C I E	H B J F	D
4	E I G C	B J H D	F
5	E G C I	D F H J	H

Figure 14C

Singly Spared Paired Table 1404

Paragraph	Group 1	Group 2	Spare
1	I C E G	J D F H	
2	C E G I	D F H J	
3	G C I E	H D J F	
4	E I G C	F J H D	
5	E G C I	F H D J	

Figure 14D

Doubly Spared Chapter Table 1406

Paragraph	Group 1	Group 2	Spare
1	I J E G	B D F H	
2	B E G I	D F H J	
3	G D I E	H B J F	
4	E I G F	B J H D	
5	E G H I	F B D J	

Figure 15

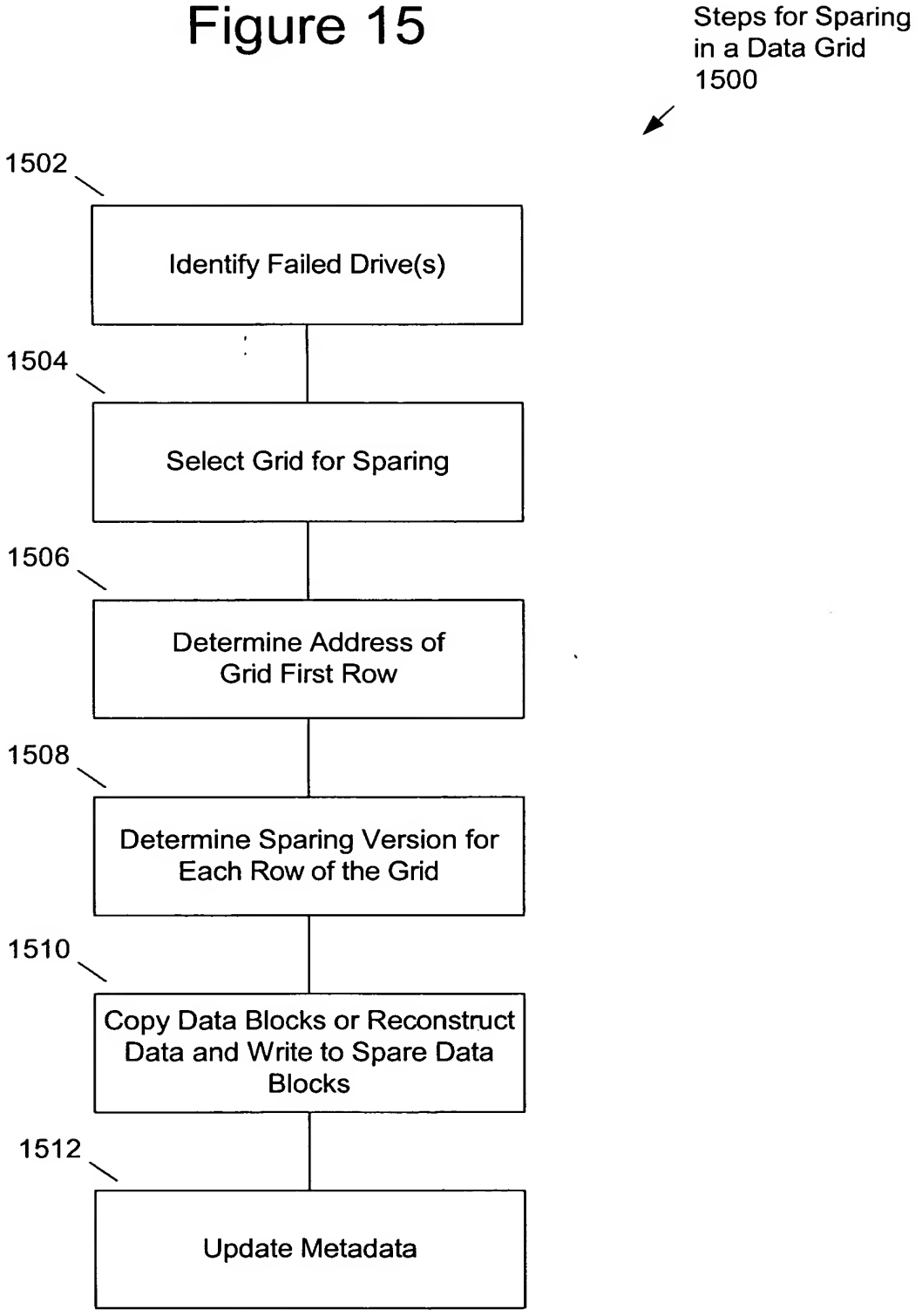
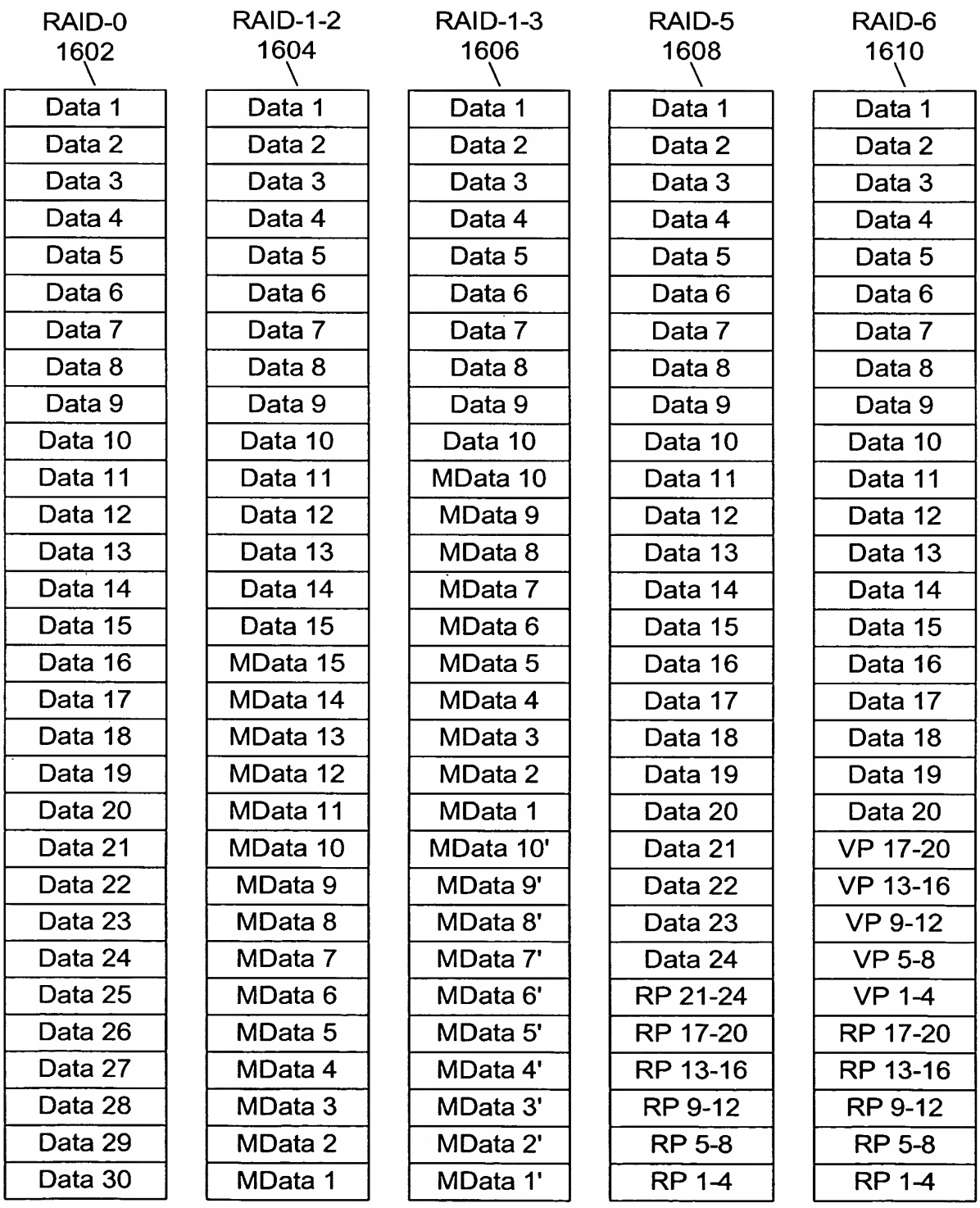

Steps for Sparing in a Data Grid 1500
1502
Identify Failed Drive(s)
1504
Select Grid for Sparing
1506
Determine Address of Grid First Row
1508
Determine Sparing Version for Each Row of the Grid
1510
Copy Data Blocks or Reconstruct Data and Write to Spare Data Blocks
1512
Update Metadata

Figure 16

Utilization Chart 1600



RAID-0 1602	RAID-1-2 1604	RAID-1-3 1606	RAID-5 1608	RAID-6 1610
Data 1	Data 1	Data 1	Data 1	Data 1
Data 2	Data 2	Data 2	Data 2	Data 2
Data 3	Data 3	Data 3	Data 3	Data 3
Data 4	Data 4	Data 4	Data 4	Data 4
Data 5	Data 5	Data 5	Data 5	Data 5
Data 6	Data 6	Data 6	Data 6	Data 6
Data 7	Data 7	Data 7	Data 7	Data 7
Data 8	Data 8	Data 8	Data 8	Data 8
Data 9	Data 9	Data 9	Data 9	Data 9
Data 10	Data 10	Data 10	Data 10	Data 10
Data 11	Data 11	MData 10	Data 11	Data 11
Data 12	Data 12	MData 9	Data 12	Data 12
Data 13	Data 13	MData 8	Data 13	Data 13
Data 14	Data 14	MData 7	Data 14	Data 14
Data 15	Data 15	MData 6	Data 15	Data 15
Data 16	MData 15	MData 5	Data 16	Data 16
Data 17	MData 14	MData 4	Data 17	Data 17
Data 18	MData 13	MData 3	Data 18	Data 18
Data 19	MData 12	MData 2	Data 19	Data 19
Data 20	MData 11	MData 1	Data 20	Data 20
Data 21	MData 10	MData 10'	Data 21	VP 17-20
Data 22	MData 9	MData 9'	Data 22	VP 13-16
Data 23	MData 8	MData 8'	Data 23	VP 9-12
Data 24	MData 7	MData 7'	Data 24	VP 5-8
Data 25	MData 6	MData 6'	RP 21-24	VP 1-4
Data 26	MData 5	MData 5'	RP 17-20	RP 17-20
Data 27	MData 4	MData 4'	RP 13-16	RP 13-16
Data 28	MData 3	MData 3'	RP 9-12	RP 9-12
Data 29	MData 2	MData 2'	RP 5-8	RP 5-8
Data 30	MData 1	MData 1'	RP 1-4	RP 1-4

Figure 17

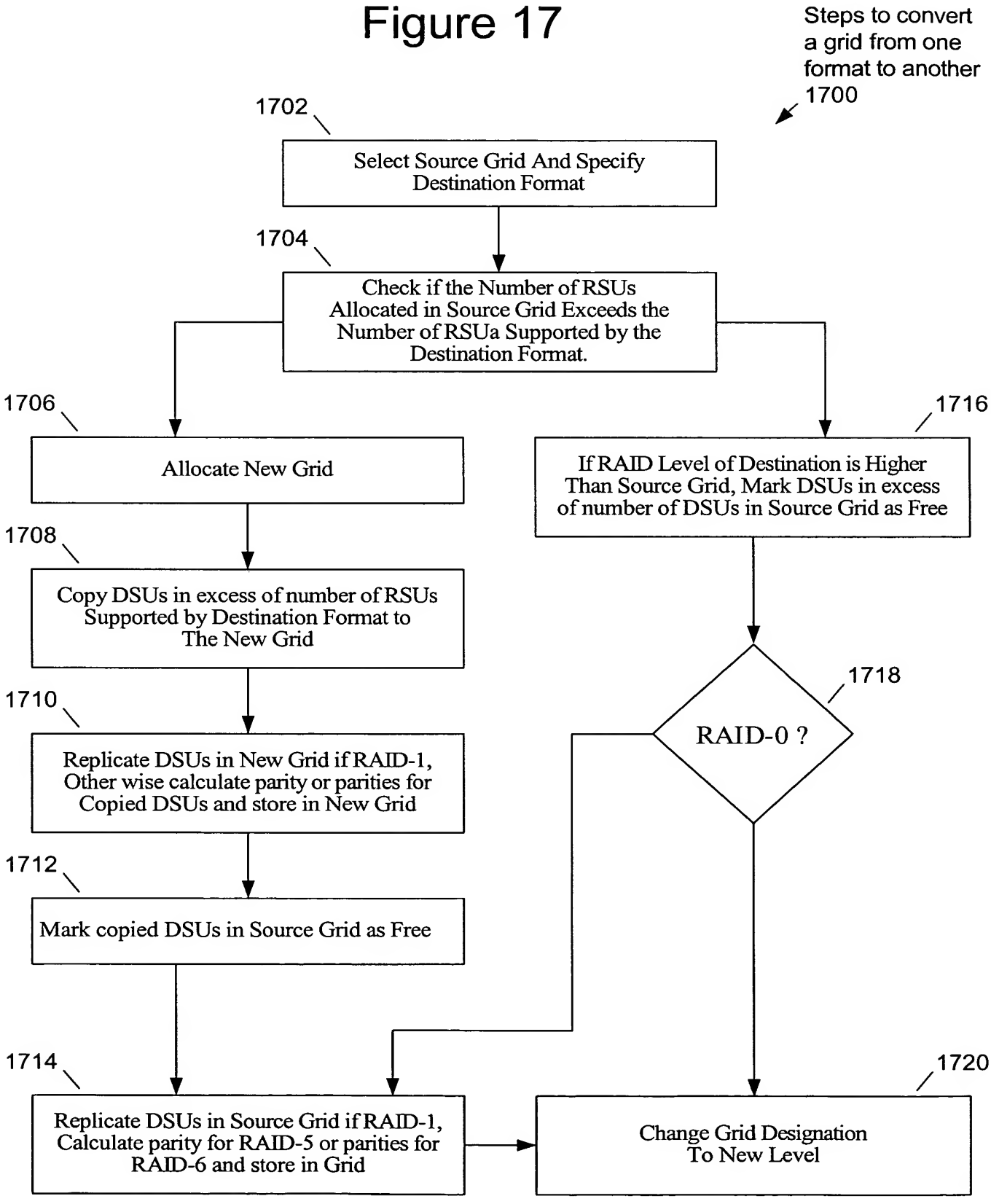

Steps to convert a grid from one format to another
1700
1702
Select Source Grid And Specify Destination Format
1704
Check if the Number of RSUs Allocated in Source Grid Exceeds the Number of RSUa Supported by the Destination Format.
1706
Allocate New Grid
1708
Copy DSUs in excess of number of RSUs Supported by Destination Format to The New Grid
1710
Replicate DSUs in New Grid if RAID-1, Other wise calculate parity or parities for Copied DSUs and store in New Grid
1712
Mark copied DSUs in Source Grid as Free
1714
Replicate DSUs in Source Grid if RAID-1, Calculate parity for RAID-5 or parities for RAID-6 and store in Grid
1716
If RAID Level of Destination is Higher Than Source Grid, Mark DSUs in excess of number of DSUs in Source Grid as Free
1718
RAID-0 ?
1720
Change Grid Designation To New Level

Figure 18

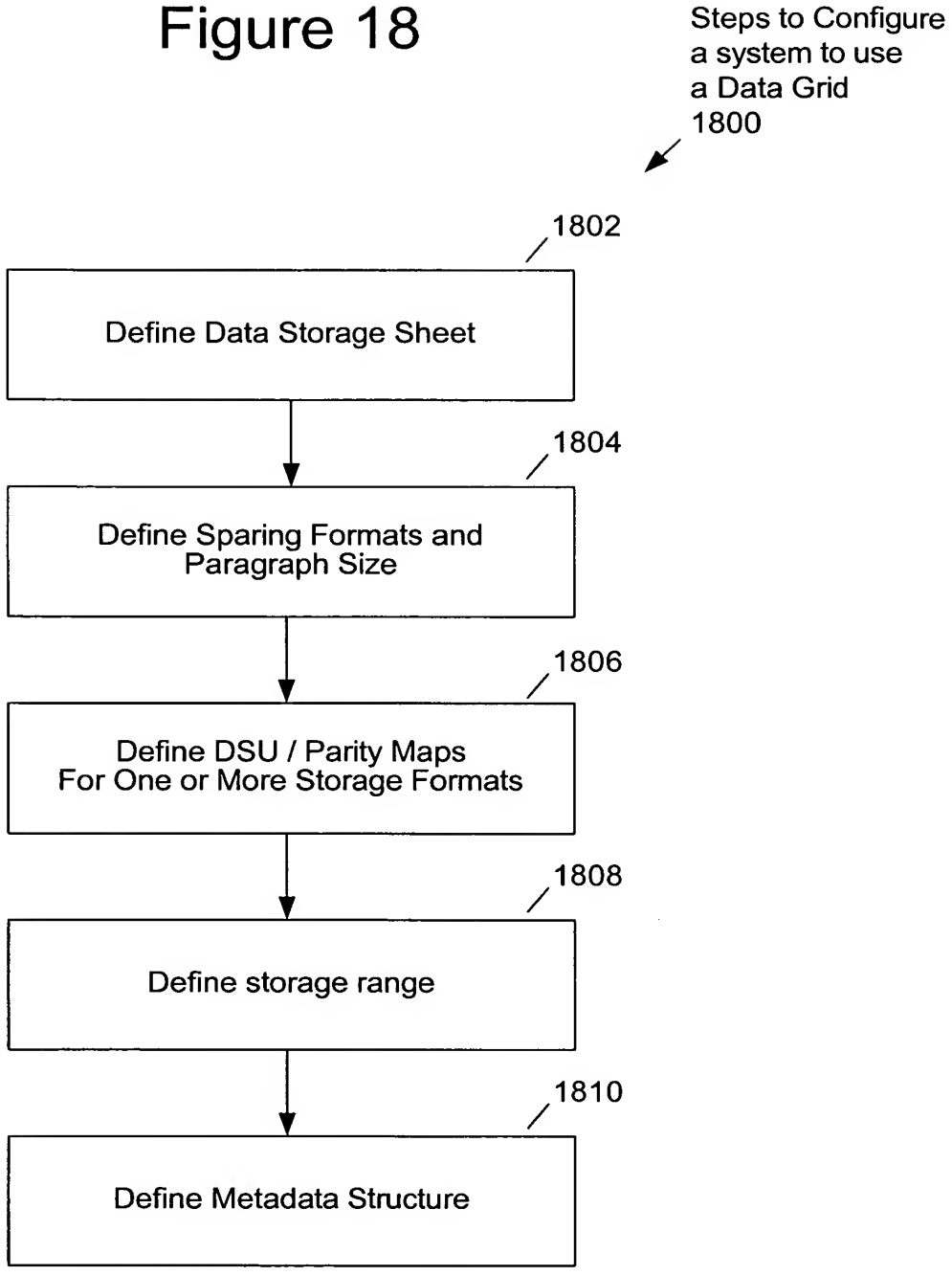

Steps to Configure a system to use a Data Grid 1800
1802
Define Data Storage Sheet
1804
Define Sparing Formats and Paragraph Size
1806
Define DSU / Parity Maps For One or More Storage Formats
1808
Define storage range
1810
Define Metadata Structure

Figure 19

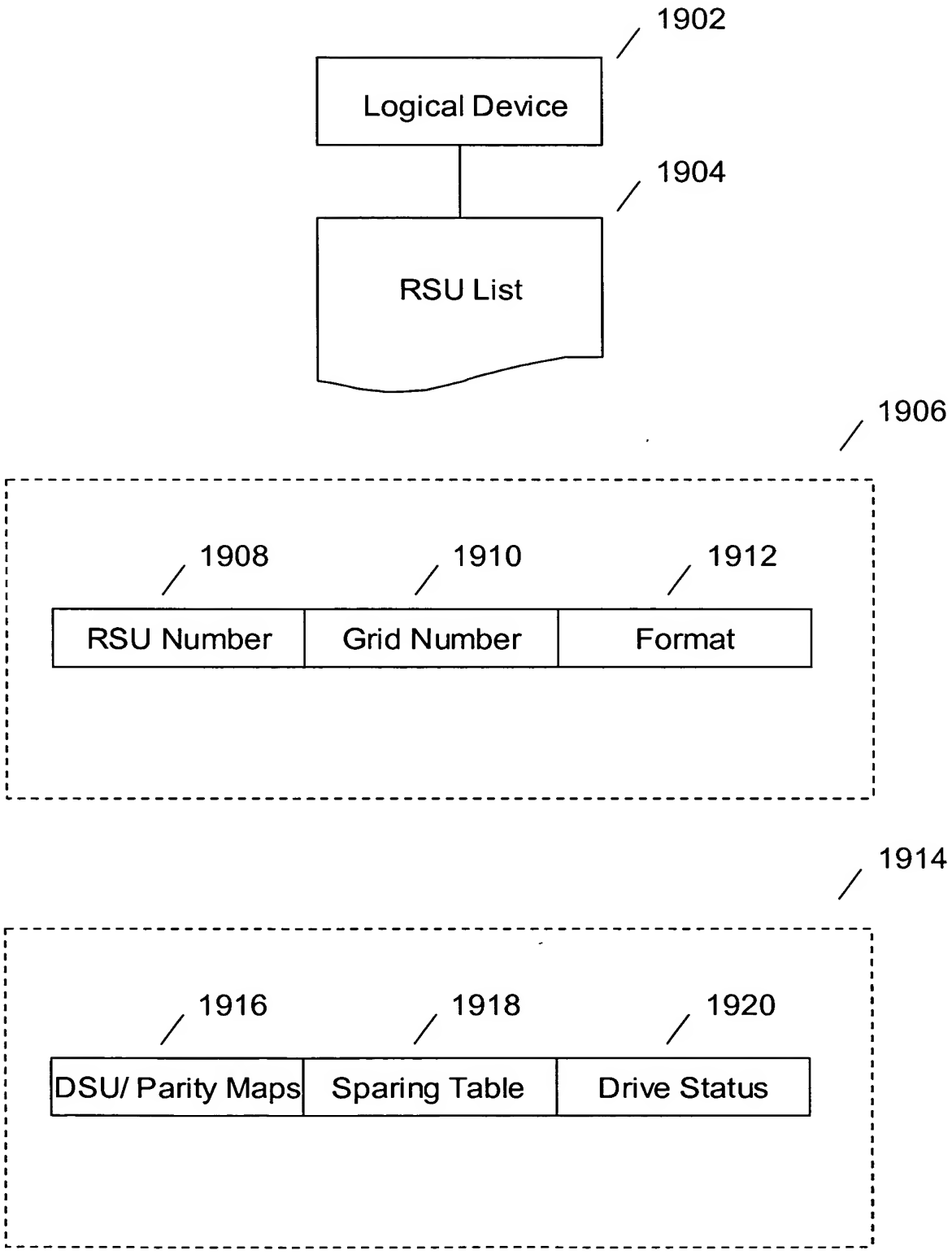
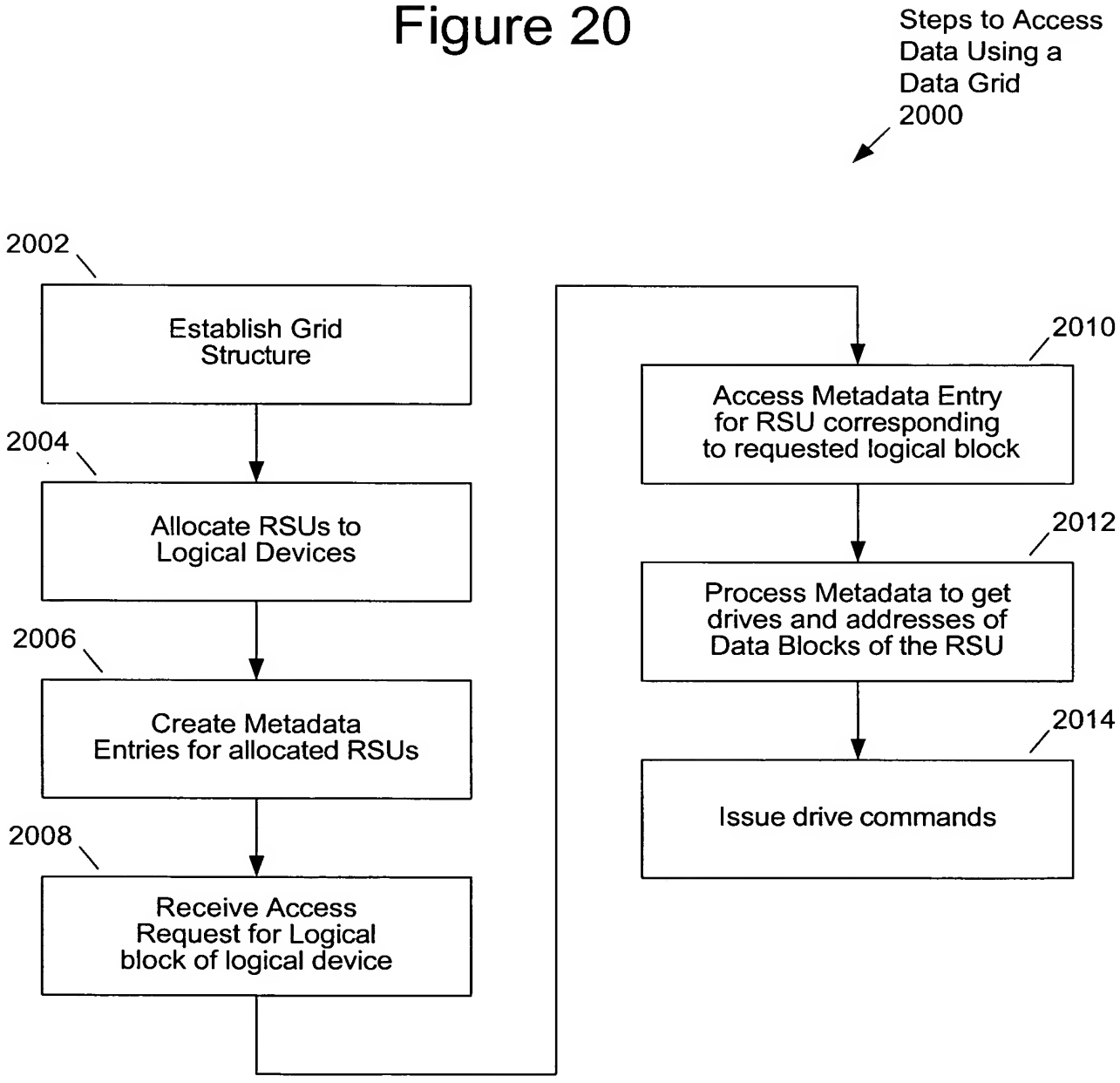

1902
Logical Device
1904
RSU List
1906
1908
1910
1912
RSU Number
Grid Number
Format
1914
1916
1918
1920
DSU/ Parity Maps
Sparing Table
Drive Status

Figure 20


Steps to Access Data Using a Data Grid
2000
2002
Establish Grid Structure
2004
Allocate RSUs to Logical Devices
2006
Create Metadata Entries for allocated RSUs
2008
Receive Access Request for Logical block of logical device
2010
Access Metadata Entry for RSU corresponding to requested logical block
2012
Process Metadata to get drives and addresses of Data Blocks of the RSU
2014
Issue drive commands